Speech Intelligibility in Cross-dialectal Multi-talker Babble

A Senior Honors Thesis

Presented in Partial Fulfillment of the Requirements for graduation

with research distinction in Speech and Hearing Sciences in the undergraduate colleges of

The Ohio State University.

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May 2009

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ABSTRACT

Informational masking occurs when speech is masked by conversational babble and affects both peripheral auditory processing and central perceptual processing. Recent studies indicate that linguistic interference contributes to informational masking but provide little information about the significant linguistic characteristics of the interference. To further examine the source of linguistic interference, this study examines whether dialect differences between multi-talker babble used as a masker and the target sentence change the effectiveness of the masker. Listeners were presented with target sentences mixed with one of each of two dialect babbles at three different levels of signal to babble ratios (S/B ratios): +5, 0 and -5 dB. Results indicated, as expected, that performance decreased significantly as the S/B ratio was decreased but there was no significant difference as a function of the number of talkers in the babble. The dialect of the babble matched to the dialect of the speaker produced significantly more masking than did the babble in the contrasting dialect (especially in the 0 dB context).

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ACKNOWLEDGMENTS

This work was supported by the Colleges of the Arts and Sciences and the College of Social and Behavioral Sciences at The Ohio State University.

I would also like to acknowledge Dr. Robert Fox and Dr. Ewa Jacewicz for their patience and guidance, as well as everyone at SPA Labs for their support on this project.

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CHAPTER 1

Introduction and Literature Review

When listening to speech, we are often confronted with competing noises and other conversations in the surrounding environment. The ability to segregate and understand speech despite such conditions is often referred to as the "cocktail party" effect (Hoen et al. 2007). Of particular interest in recent studies are situations in which speech is masked by conversational babble. Recent studies indicate that the acoustic-phonetic and linguistic content of the competing conversational babble (i.e. lexical and sub-lexical items and prosody) contribute to the decrease in intelligibility of the target speaker (e.g., Simpson and Cooke 2005; Van Engen and Bradlow, 2007). The present study aims to further investigate the linguistic factors that contribute to such listening conditions by varying the dialect of the conversational babble masking the target speaker.

1.1 Masking

It is well established that the presence of background noise results in a reduction in speech intelligibility (e.g., Miller 1947). The greater the level of noise relative to the level of speech presented to listeners, the greater the reduction of intelligibility. The masking effect is in part due to overlapping of noise in time and frequency (Hoen et al. 2007). When this occurs, the amount of stimulus information available for peripheral processing (i.e. the physiological mechanisms for hearing) is reduced (Kidd et al., 2007). This form of masking is often referred to as energetic masking.

It is acknowledged, however, that the energetic overlapping of noise is not the only contributing factor to the overall masking effect when speech is masked by conversational babble. As cited in Kidd et al. (2007), Carhart et al. (1969) found that a masker containing meaningful speech caused significantly more masking than expected based on the spectral makeup of the maskers. Carhart et al. (1969) described this masking as "perceptual" because it was thought to be due to higher levels of processing (i.e. linguistic processing). Masking that cannot be attributed to the physical interaction between the signal and the masker has more recently been referred to as informational masking (Hoen et al., 2007; Brungart et al., 2001). When speech is masked my conversational babble, energetic masking does occur, but the masking effect is in large part due to informational masking, not energetic masking (Hoen et al., 2007).

The literature discusses several variables that affect the amount of masking present during speech-in-speech comprehension, including: signal-to-noise ratio (SNR), number of talkers in the babble, and characteristics of the speakers in both the target and the background speech (Brungart et al., 2001). In regards to voice characteristics, studies generally show that background speech that is less similar to the target speaker generally allows for greater intelligibility of the target. Brungart et al. (2001) found that performance among listeners decreased when the masker and the target were of the same sex versus being presented with a different-sex masker.

Studies investigating both speech-in-noise and speech-in-speech perception have found that listeners' performance decreases as the level of the noise increases (Van Engen and Bradlow, 2007). Various studies have also concluded that the number of talkers in the background also has an effect on listeners' performance. Simpson and Cooke (2005) found that as the number of speakers in conversational babble increases, performance among listeners decreased. However, intelligibility of the target signal remained generally the same for babble containing 6 to 128 talkers. The study compared this finding to intelligibility of babble-modulated noise. The natural babble was a more effective masker when there were at least 3 talkers present. These results indicate that more energetic masking is present when more talkers are in the signal, as there are fewer temporal gaps in the masker (Van Engen and Bradlow, 2007). On the other hand, linguistic interference only contributes to masking when there are few talkers in the signal (Simpson and Cooke 2005).

Simpson and Cooke's (2005) findings indicate the presence of linguistic interference when speech is masked by conversational babble. However, the majority of the studies investigating speech-in-speech perception involved maskers that contained speech of the same language as the target speech, and provide little information regarding this linguistic interference. Van Engen and Bradlow (2007) recently found that the language of the babble affects listeners' performance. The study compared intelligibility of English target sentences masked by either English or Mandarin Chinese when presented to native English listeners. The findings indicate that the language of the babble does significantly affect listeners' performance. The English babble provided significantly more masking than the Mandarin babble. The results in this study also found that linguistic factors have a greater affect on the overall masking when there are fewer speakers present and when the level of the target is equal or less than the level of the masker. As the languages in this study differ greatly in linguistic characteristics, the findings provide little information regarding the source of the language effect. Other variations of the babble masker, including the dialect of the masker, could provide further insight about this phenomenon. The present study compares intelligibility of target sentences masked by two different dialects that vary greatly in acoustic-phonetic characteristics but do not vary systematically in terms of phonological structure or lexical items.

1.2 Dialect Perception

Recent studies suggest the importance of acoustic-phonetic information in speech perception across dialects (Clopper and Bradlow 2008, Labov 2006). Clopper and Bradlow (2008) investigated intelligibility of speech from various dialects in noise. Listeners had higher intelligibility when the speech was in the General American English category which included less marked dialects (e.g. regions including New England, the West, and the Midland region). In the more adverse listening conditions (i.e. higher SNR), listeners made more transcription errors in more marked dialects including the Mid-Atlantic, Northern, and Southern regions. The dialect of the listeners was not significant, however, the sample of listeners in this study did not adequately cover the dialects presented in the listening experiment. Thus, it is not clear whether Southern listeners would perform better when presented by their own dialect or the General American dialect. However, the effect of dialect in this study does indicate that listeners are sensitive to dialect variation in language. Clopper and Bradlow (2008) describe several possible explanations for this sensitivity at higher SNRs including that listeners may be less able to map the acoustic-phonetic cues, especially with more marked dialects. This study demonstrates the importance of acoustic-phonetic cues of dialects on the perception of speech.

1.3 The present study

The present study aims to expand on the recent findings indicating the contribution of linguistic interference to informational masking as well as the importance of acoustic-phonetic cues in speech processing. This study compares the intelligibility of speech masked by two distinct dialects. The target dialect in this study is often referred to as the Midland dialect (Labov et al. 2005). This dialect is often found in the Mid-Atlantic states. For the purpose of this study, the native Midland speakers consist of those who have spent the majority of their life in the Central Ohio region. The contrasting dialect in this study is an Appalachian dialect, sometimes referred to as the Inland South. For the purpose of this study, native speakers of this dialect had spent the majority of their lives in the Western region of North Carolina. The Appalachian dialect features the most advanced stages of the Southern Shift. The Southern Shift affects the pronunciations of several vowels including a more fronted /u/. The acoustic-phonetic features of the Appalachian dialect differ greatly from the Midlands dialect. The marked differences in acoustic-phonetic features of these dialects will maximize any effect dialect has on intelligibility.

CHAPTER 2

Methodology

2.1 Babble Speakers

The speech used in the babble was recorded for a previous study in the SPA Labs and featured spontaneous natural speech. For the current study the speakers chosen for the creation of the babble included twelve male speakers (aged 50 to 70 years). Of the twelve, six were speakers of a Midlands dialect of American English (spoken in Central Ohio), and six were speakers of the Appalachian dialect of American English (spoken in western North Carolina) which features the Southern Vowel Shift. All of the speakers had a similar fundamental frequency and of the same gender in order to avoid any influence of voice quality differences on the intelligibility of the target speech (Brungart et al., 2001).

2.2 Babble Creation

Short individual phrases of the recorded conversations were extracted from each speaker's discourse. Each phrase contained approximately 5 to 10 syllables (e.g. "quite a few more restaurants" and "not as well educated and"). These samples were amplitude normalized and reordered using Adobe Audition 1.0 waveform editing program to make the speech semantically anomalous in order to eliminate syntactic and semantic effects (one could not follow any "story" by listening to the babble individually, one could hear individual words but one could not predict it in advance). The reordered recordings were then copied and added to the end to create one long sound file for each speaker. Each sound file was amplitude normalized using Adobe Audition 1.0.

Two speakers from each dialect were chosen for creation of the 2-talker babble. Selection of these speakers was based on similarity between the voice quality of the speaker and target speaker. This was done in order to eliminate extraneous factors that may interfere with the perception experiment. With the control of a MATLAB program, these speakers were combined into a single file to create the 2-talker babble in each dialect. All 6 speakers were combined to create the 6-talker babble. Each combined recording was then divided into 120 samples, each 4 seconds long. The beginning of the each sample included the end of the previous sample. Due to this, the repeated sections of the recording delivered different samples because the starting point of the sample was in a different location. This created 120 samples in each of the babble conditions (2-talker Ohio dialect babble, 2-talker North Carolina dialect babble, 6-talker Ohio dialect babble, and 6-talker North Carolina dialect babble).

2.3 Target Sentences

A male speaker of the Midlands dialect who was born and grew up in the Columbus, Ohio area, was recorded for the target speech.   This speaker met the same criteria as the speakers used in the babble for age and fundamental frequency. The speaker read sentences from the Revised Bamford-Kowal-Bench Standard Sentence Test lists 3, 4, 6, 7, 9, 13, 18. Each list has 16 short, simple sentences (e.g., *The book tells a story.*). All sentences are listed in Appendix. A. Each sentence has 2 to 3 keywords and a total of 50 keywords per list. Six of the lists were used for the experimental section for a total of 300 keywords. The recordings took place in a sound-attenuating booth using a head-mounted Shure SM10A microphone positioned

1-inch from the speaker's lips. All sentences were recorded directly to a hard disk drive at a sampling rate of 44.1 kHz and a quantization rate of 16 bits. The recordings were peak amplitude-normalized before its overall amplitude was adjusted when being combined with the babble speech.

2.4 Listeners

Participants in the listening test included young adults who were born, raised, and lived in Central Ohio (determined to be within approximately 60 miles of Columbus, OH). The group consisted of 23 listeners, 6 male and 17 female, all between the ages of 20-28. Each participant was paid $10.00 for participating in the 30 to 60 minute long experiment. All participants reported normal hearing. 13 of the participants completed perception test in the 2-speaker condition and 10 participants completed the 6-speaker condition.

2.5 Procedure

The perception test was conducted in the SPA Labs. Listeners were tested individually. Each listener was seated in a sound attenuating booth and listened to target sentences mixed with either the 2-talker or 6-talker babble, delivered over Sennheizer HD 600 circumaural headphones at a comfortable listening level (~70 dB HL). The test was administered under the control of a MATLAB program. For each testing block, the experimenter selected the number of speakers, dialect, and signal-to-babble ratio. Each babble segment was 4 seconds long and a sentence was positioned within the center 75% of the babble. The actual position of the sentence was randomly varied within this location (thus listeners could not predict the exact timing of the target sentences' onset). The onset and offset of the mixed token was ramped from/to zero using a Hanning window over the first and last 5 milliseconds. After the random selection of the babble occurred for each trial, levels of the babble and sentence were appropriately adjusted. Participants faced a computer monitor and were asked to type the target sentence they heard into a box that appeared on the screen after each target and babble combination.

Participants either completed the perception experiment with target sentences masked by 2-talker or 6-talker babble Each participant was presented with 100 sentences total (4 sentences in the practice block followed by 6 experimental blocks containing 16 sentences each). Participants completed six experimental blocks. In the first block, participants listened to the target masked by North Carolina babble at a signal-to-babble ratio of +5 dB. For the second block, the babble was Ohio and still at a signal-to-babble ratio of +5 dB. The listeners were presented with blocks in the same order at signal-to-babble ratios of 0 dB and -5 dB (see Table 2.1). The practice block featured babble that was mixed with both Ohio speech and North Carolina speech and was presented at a babble-to-signal ratio of +5 dB.

Table 2.1. Experimental design: conditions, blocks.

Condition	Number of Talkers in Babble	Block 1 North Carolina Dialect	Block 2 Ohio Dialect	Block 3 North Carolina Dialect	Block 4 Ohio Dialect	Block 5 North Carolina Dialect	Block 6 Ohio Dialect
1	2	S/B Ratio: +5	S/B Ratio: +5	S/B Ratio: 0	S/B Ratio: 0	S/B Ratio: -5	S/B Ratio: -5
2	6	S/B Ratio: +5	S/B Ratio: +5	S/B Ratio: 0	S/B Ratio: 0	S/B Ratio: -5	S/B Ratio: -5

It was predicted that blocks would become more difficult as the S/B ratio decreased due to the greater level of noise and energetic masking, and that the Ohio babble would be more difficult than the North Carolina babble due to linguistic interference. Therefore, each participant was first presented with North Carolina, followed by Ohio. Participants were also first presented with the easiest S/B ratio (i.e. +5 dB) which was then decreased after the listener was presented with two blocks (one for each dialect) at this level. This enabled the participants to become comfortable with the task and the target speaker before arriving at the difficult condition. All participants were presented with the blocks in the same order as described in Table 2.1.

2.6 Data Analysis

Scoring was based on the keywords provided by the Revised Bamford-Kowal-Bench Standard Sentence Test. Each sentence had 2 or 3 keywords for a total of 50 keywords per set of 16 sentences. The scoring criteria were adapted from the Van Engen and Bradlow's (2006) study investigating speech perception in babble. Only correct responses, spelling errors, and homophones were counted as correct. A word was not counted correct if it had any added, deleted, or incorrect morphemes[1].

The results for each subject in each of six experimental conditions were tabulated and transformed into a percentage correct score. However, as is well known, the variance of percentage (and proportion) correct scores is not independent of the mean of these scores (due to ceiling and basement effects) and thus they violate the homogeneity of variance assumption required in many statistical tests. Thus prior to the analysis of these data, the percentage correct scores were arcsine transformed into rationalized arcsine units or RAUs (see Studebaker, 1985). On this scale, -23 RAU corresponds to 0% correct and ranges to +123 RAU which corresponds to 100% correct.

[1] A modified method of scoring was also used to give subjects partial credit for answers. However, since the pattern of results was the same for both methods, only the results based on the Van Engen and Bradlow methodology is presented.

CHAPTER 3

Results

3.1 Results

The results for each subject in each of six experimental conditions were tabulated and transformed into a percentage correct score. Mean percentage correct scores are presented in Figures 3.1 to 3.3. However, as noted in the Methodology section, all statistical analyses were completed using the rationalized arcsine transforms.

These arcsine-transformed data were analyzed using a 3-way repeated measures analysis of variance (ANOVA) with the within-subject factors *S/B ratio* (+5 dB, 0 dB, -5 dB) and *dialect of babble* (Ohio babble or North Carolina babble) and the between-subject factor *babble group* (2-speaker babble or 6-speaker babble).

3.2 Babble group

There was no significant effect of babble group ($F(1,21)=3.31$ $p>.05$) although listeners showed slightly better performance in the 2-speaker condition (65.7%) than in the 6-speaker condition (59.8%). This is illustrated in Figure 3.1, separately for each group at each signal-to-babble ratio

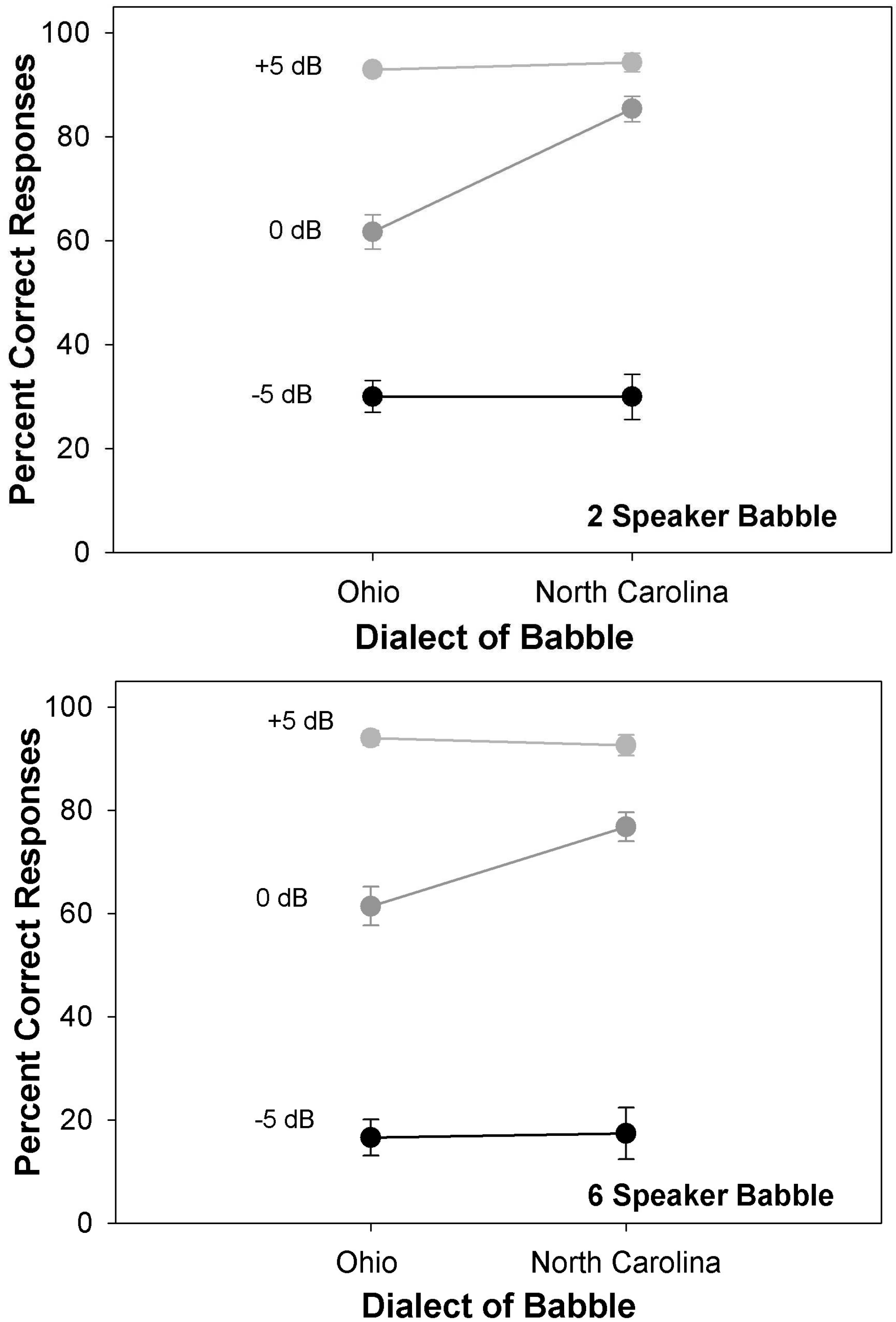

Figure 3.1 Relation between Group (i.e. 2-talker or 6-talker babble), Signal-to-Babble ratio, and dialect.

3.3 Signal-to-Babble Ratio

As expected, there was a significant effect of S/B ratio (F(2,42)=578.8, p<.001). Listeners performed more poorly as the level of the signal (the sentences) decreased relative to the level of the babble. Subjects performed very well at the highest S/B ratio and very poorly at the lowest S/B ratio. The mean percentages correct for the +5 dB, 0 dB and -5 dB ratios were 93.5%, 72.3% and 23.4%, respectively. Figure 3.2 illustrates this effect separately for each group.

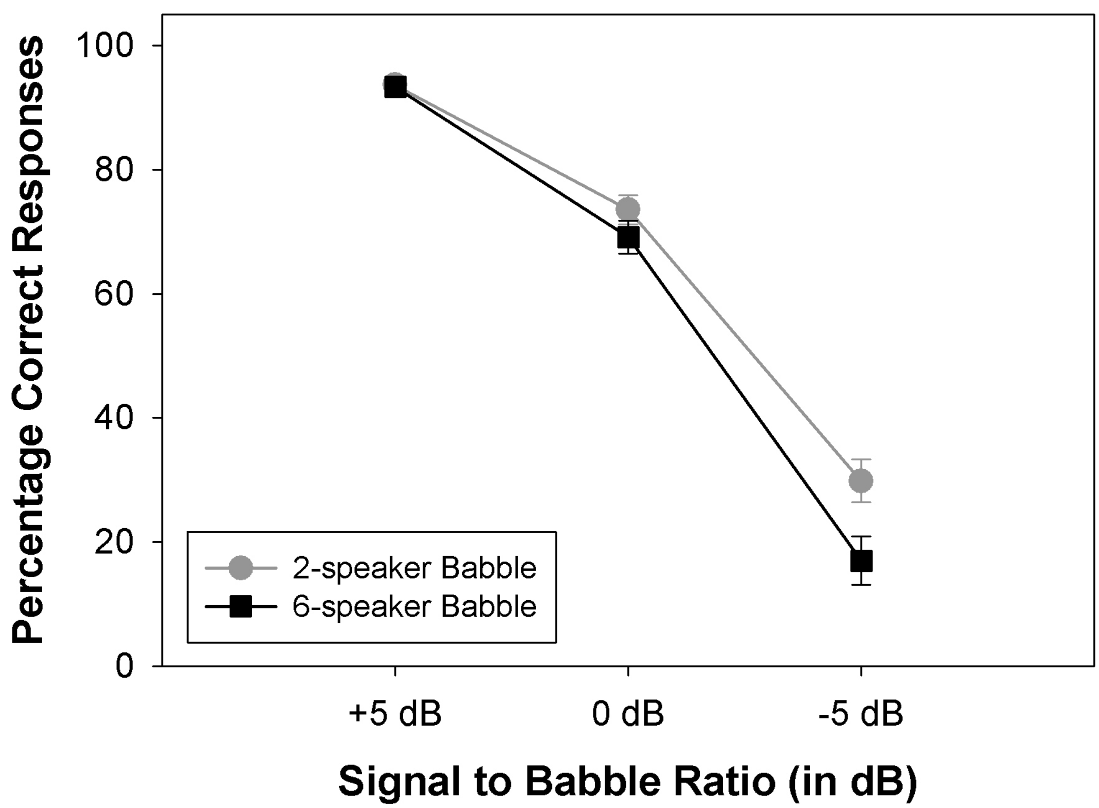

Figure 3.2 Relation between Signal-to-babble ratio and group (i.e. 2 talker or 6 talker babble)

3.4 Dialect

Of particular interest in this study, however, is the effect of variation in the dialect of the babble upon listener performance. There was a significant effect of the dialect of babble on listener performance ($F(1,21)=13.6$, $p=.001$). The percentage of correct responses was significantly lower when the sentences were embedded in Ohio babble (59.436%) than in North Carolina babble (66%) as illustrated in Figure 3.3. In addition, there was a significant dialect by S/B ratio interaction ($F(2,42)=20.4$, $p<.001$). This significant interaction arises from the fact that while the performance levels for the +5 dB and -5 dB for the Ohio babble (93.5% and 23.3%, respectively) and the North Carolina babble (93.5% and 23.5%) were practically identical, the percentage correct level in the 0 dB for the North Carolina babble (81.1%) was more then 20% higher than for the Ohio babble. Clearly, the effect of dialect is strong in the 0 dB condition. None of the other interaction effects were significant.

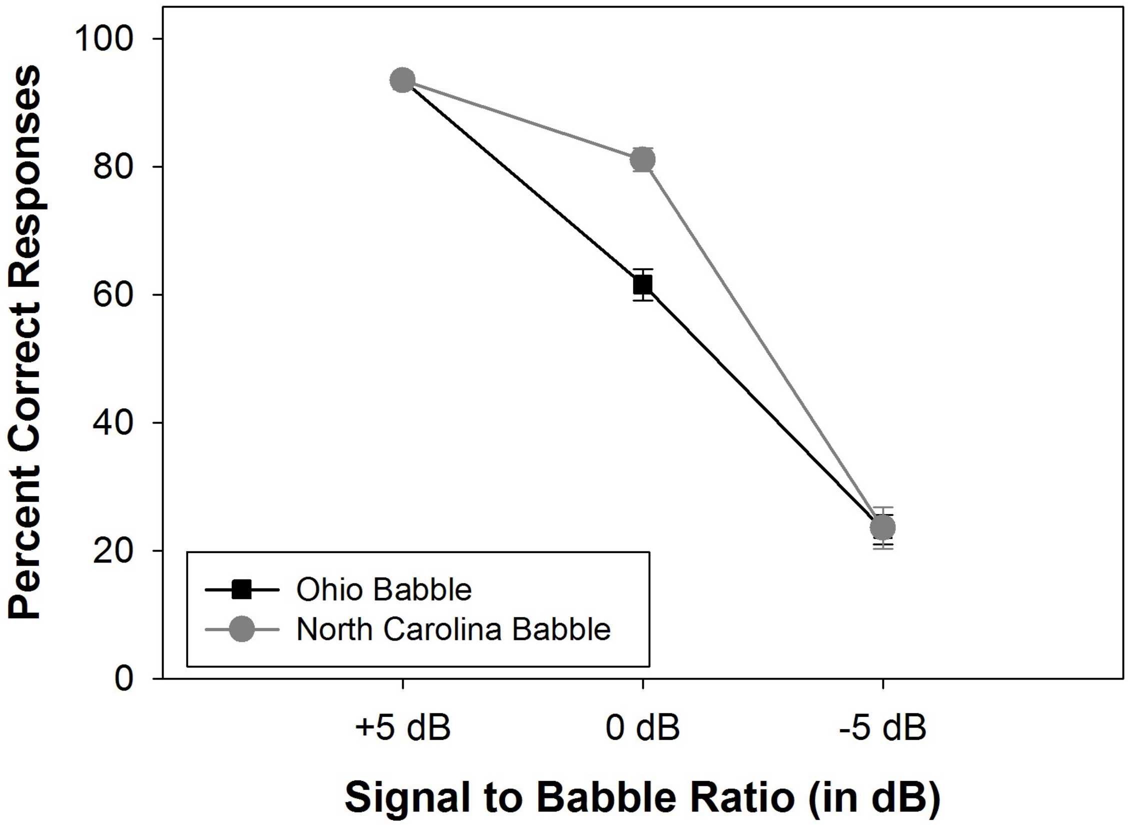

Figure 3.3 Relation between dialect and signal to babble ratio.

CHAPTER 4

Discussion and Conclusions

While previous studies have indicated the effect of linguistic interference during speech-in-speech perception, little research had analyzed the linguistic factors involved in the masking effect. The current study investigated intelligibility of speech masked by two different dialects. The first dialect (i.e. the Midlands dialect) matched the dialect of the target speaker and that of the listeners in the study. The second dialect chosen for this study was the Appalachian dialect which varies greatly in acoustic-phonetic characteristics from the Midlands dialect. The results indicate that intelligibility improved when the background babble featured the contrasting dialect.

Listeners' performance decreased as the signal to babble ratio decreased, as expected based on findings from previous studies (Van Engen and Bradlow 2006, Brungart et al. 2001) . The effect of dialect was significant when the level of the target speaker and the babble was the same (i.e. a signal-to-babble ratio of 0 dB). This result is similar to the findings of Van Engen and Bradlow (2006) who found the effect of language to be significant in more difficult listening conditions (i.e. listeners' performed better when presented with Mandarin babble relative to the English babble only in conditions where the level of the target was equal or lower than the babble). In the present study, however, the effect of dialect was only significant when the levels of the target speaker and the babble were equal, and not when the level of the babble was greater relative to the target speaker. This may be due to greater informational masking present by both dialects in comparison to presenting babble of a different language. When the level of the masker was higher than the target, listeners performed very poorly and thus, no difference between the dialects emerged.

In the present study, dialect had a significant effect in both 2-talker and 6-talker conditions. This is in contradiction to the results found by Van Engen and Bradlow (2006) in which the language of the babble only had a significant effect in the 2-talker condition. Previous studies have also found that performance decreases as the number of talkers increases (Simpson and Cooke 2005). While there was no significant effect of the number of speakers on intelligibility in the present study, listeners did tend to perform better in the 2-talker condition than the 6-talker condition. Further investigation is required to determine how the levels of energetic and informational masking vary with the number of talkers in the babble.

While this study indicates that listeners are sensitive to the acoustic-phonetic differences present in dialects in speech-in-speech perception, exactly how these factors contribute to the overall masking has not been determined. Many studies have indicated that greater similarity between talkers causes greater masking of the target (Brungart et al., 2001). Studies examining dialect perception have shown that listeners are sensitive to acoustic-phonetic characteristics in marked dialects. Therefore, it is possible that this effect could be due to the level of similarity between talkers, or to interference due to linguistic processing of the dialects in the background. Future research could expand upon this by investigating other variations of the target and the babble. For example, future studies could investigate whether listeners of other dialects perform similarly and how listeners are affected when the target is different from their native dialect (e.g. presenting Ohio listeners with target sentences spoken by a speaker from North Carolina). This could provide insight as to whether the effect is due to talker similarity or due to the listener "tuning in" to his or her native dialect more than the nonnative dialect.

Conclusion

The results indicate that dialect and signal-to-babble ratio have a significant effect on performance. Consistent with previous speech-in-babble studies, performance decreased as the signal-to-babble ratio decreased. The Ohio babble produced more informational masking than the North Carolina babble. The effect of dialect on performance was most significant when the signal-to-babble ratio was at 0dB. These findings support predictions based on previous studies indicating that linguistic interference contributes to informational masking (e.g., Van Engen & Bradlow, 2006). This study varied the dialect of the babble, unlike previous studies which varied the language of the babble. These findings provide further insight into the source of linguistic interference in speech-in-speech comprehension.

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APPENDIX

The following sentences were recorded by a male speaker from Central Ohio. Each set was randomly reordered before being presented to the participants. These sentences were taken from lists 3, 4, 6, 7, 9, 13, and 18 of the Revised Bamford-Kowal-Bench Standard Sentence Test. Scoring of the perception test was based on the number of keywords the listener correctly identified. These keywords are underlined.

Practice

The child grabbed the toy.
They watched the movie.
The tomatoes grew in his garden.
It is time to go home.

Set 1

1. The <u>book</u> <u>tells</u> a <u>story</u>.
2. The <u>young</u> <u>boy</u> <u>left</u> <u>home</u>.
3. <u>They</u> are <u>climbing</u> the <u>tree</u>.
4. <u>She</u> <u>stood</u> near her <u>window</u>.
5. The <u>table</u> has <u>three</u> <u>legs</u>.
6. A <u>letter</u> <u>fell</u> on the <u>floor</u>.
7. The <u>five</u> <u>men</u> are <u>working</u>.
8. <u>He</u> <u>listened</u> <u>to</u> his <u>father</u>.
9. The <u>shoes</u> were <u>very</u> <u>dirty</u>.
10. <u>They</u> <u>went</u> on a <u>vacation</u>.
11. The <u>baby</u> <u>broke</u> his <u>cup</u>.
12. The <u>lady</u> <u>packed</u> her <u>bag</u>.
13. The <u>dinner</u> <u>plate</u> is <u>hot</u>.
14. The <u>train</u> is <u>moving</u> <u>fast</u>.
15. The <u>child</u> <u>drank</u> some <u>milk</u>.
16. The <u>car</u> <u>hit</u> a <u>wall</u>.

Set 2

1. The <u>bakery</u> <u>is</u> <u>open</u>.
2. <u>They</u> <u>like</u> <u>orange</u> <u>marmalade</u>.
3. <u>Mother</u> <u>shut</u> the <u>window</u>.
4. <u>He</u> is <u>skating</u> <u>with</u> his <u>friend</u>.

5. The apple pie was good.
6. Rain falls from the clouds.
7. She talked to her doll.
8. They painted the wall.
9. The towel dropped on the floor.
10. The dog is eating some meat.
11. A boy broke the fence.
12. The yellow pears tasted good.
13. The police helped the driver.
14. The snow is on the roof.
15. The lady washed the shirt.
16. The cup is hanging on a hook.

Set 3

1. The paint dripped on the ground.
2. Mother stirred her tea.
3. They laughed at his story.
4. Men wear long pants.
5. The small boy was asleep.
6. The lady went to the store.
7. The sun melted the snow.
8. The father is coming home.
9. She had her spending money.
10. The truck drove up the road.
11. He is bringing his raincoat.
12. A sharp knife is dangerous.
13. They took some food.
14. The smart girls are reading.
15. The broom stood in the corner.
16. The woman cleaned her house.

Set 4

1. The children dropped the bag.
2. The dog came back.
3. The floor looked clean.

4. She found her purse.
5. The fruit is on the ground.
6. Mother got a saucepan.
7. They washed in cold water.
8. The young people are dancing.
9. The bus left early.
10. They had two empty bottles.
11. The ball is bouncing very high.
12. Father forgot the bread.
13. The girl has a picture book.
14. The orange was very sweet.
15. He is holding his nose.
16. The new road is on the map. 3

Set 5

1. The fruit came in a box.
2. The husband brought some flowers.
3. They are playing in the park.
4. She argued with her sister.
5. A man told the police.
6. Potatoes grow in the ground.
7. He is cleaning his car.
8. The mouse found the cheese.
9. They waited for one hour.
10. The big dog was dangerous.
11. The strawberry jam was sweet.
12. The plant is hanging above the door.
13. The children are all eating.
14. The boy has black hair.
15. The mother heard the baby.
16. The truck climbed the hill.

Set 6

1. The glass bowl broke.
2. The dog played with a stick.

3. The teapot is very hot.
4. The farmer keeps a bull.
5. They say some silly things.
6. The lady wore a coat.
7. The children are walking home.
8. He needed his vacation.
9. Milk comes in a carton.
10. The man cleaned his shoes.
11. They ate the lemon pie.
12. The boy is running away.
13. Father looked at the book.
14. She drinks from her cup.
15. The room is getting cold.
16. A girl kicked the table.